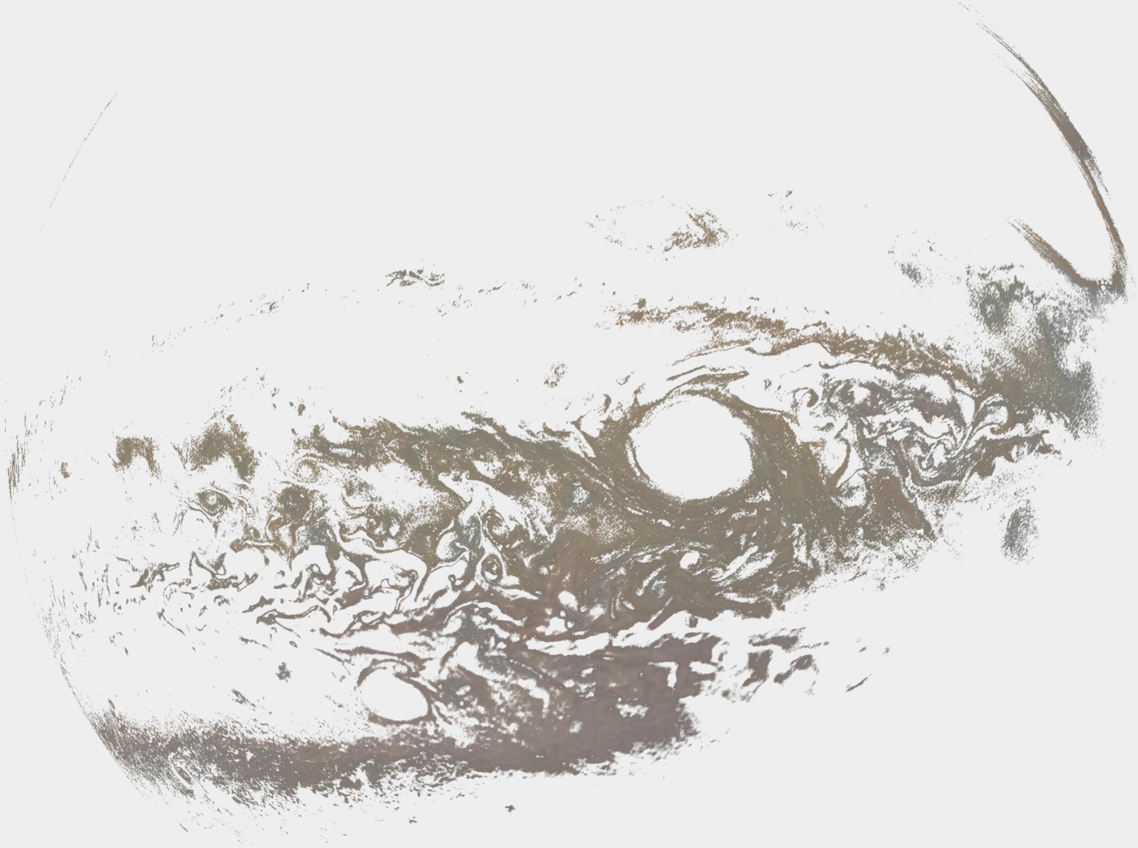


University of Zurich^UZH^

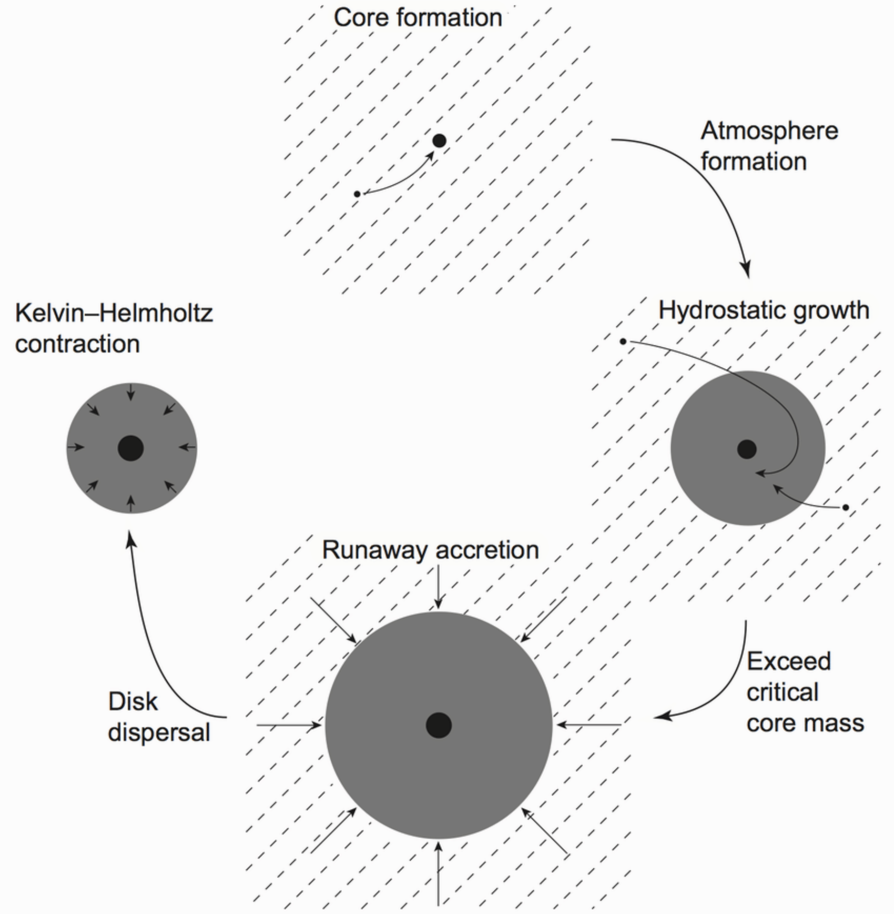
Evolution of Giant Planets with Composition Gradients: Connecting Atmospheric Measurements to Bulk Composition

Simon Müller, Ravit Helled, Andrew Cumming, Maia Ben Yami

ARIEL: Science, Mission & Community 2020 Conference

Why do we care about heavy elements in giant planets?

i) Testbed for Formation Theory

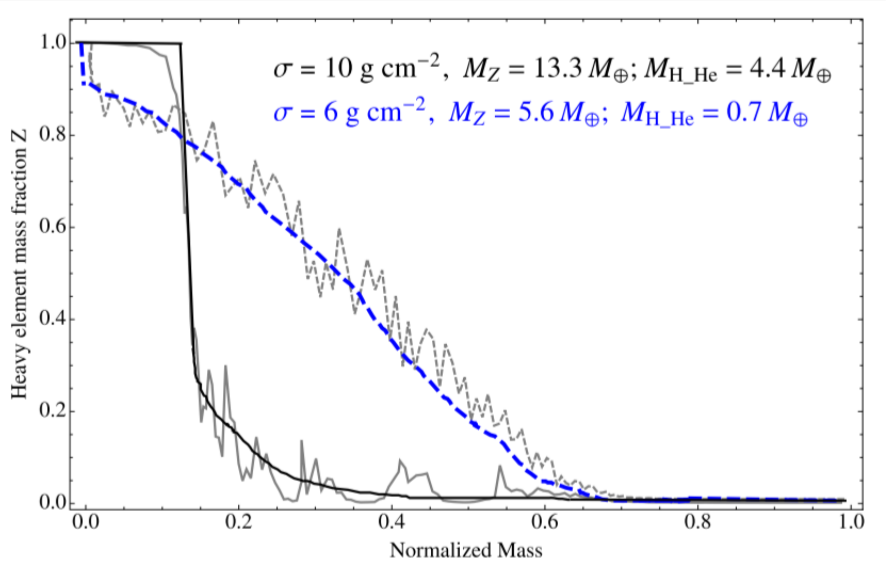


Credits: Phil Armitage

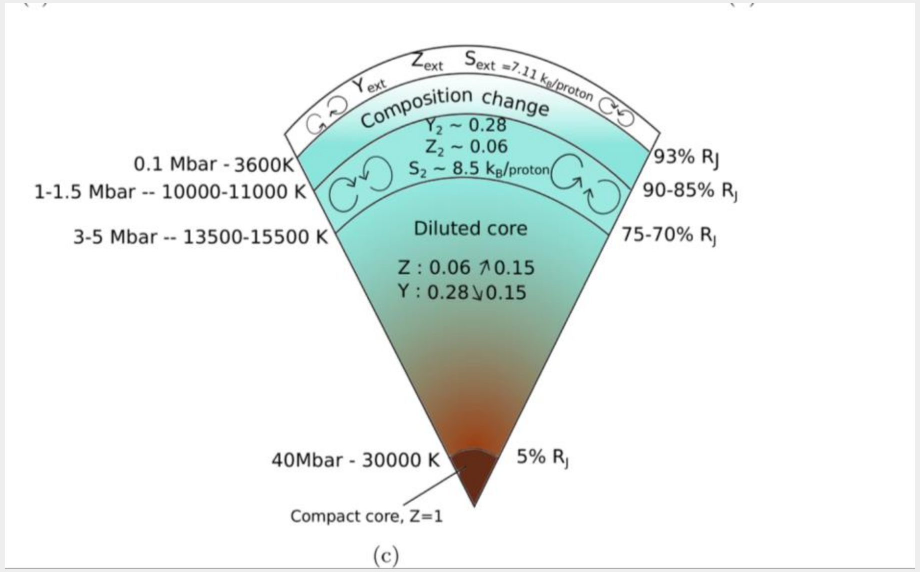
ii) Influence on Evolution and Internal Structure

- Radiative regions: No mixing, inefficient energy transport.
- Convective regions: Efficient mixing and energy transport.
- ***Convection can be inhibited by a composition gradient.***

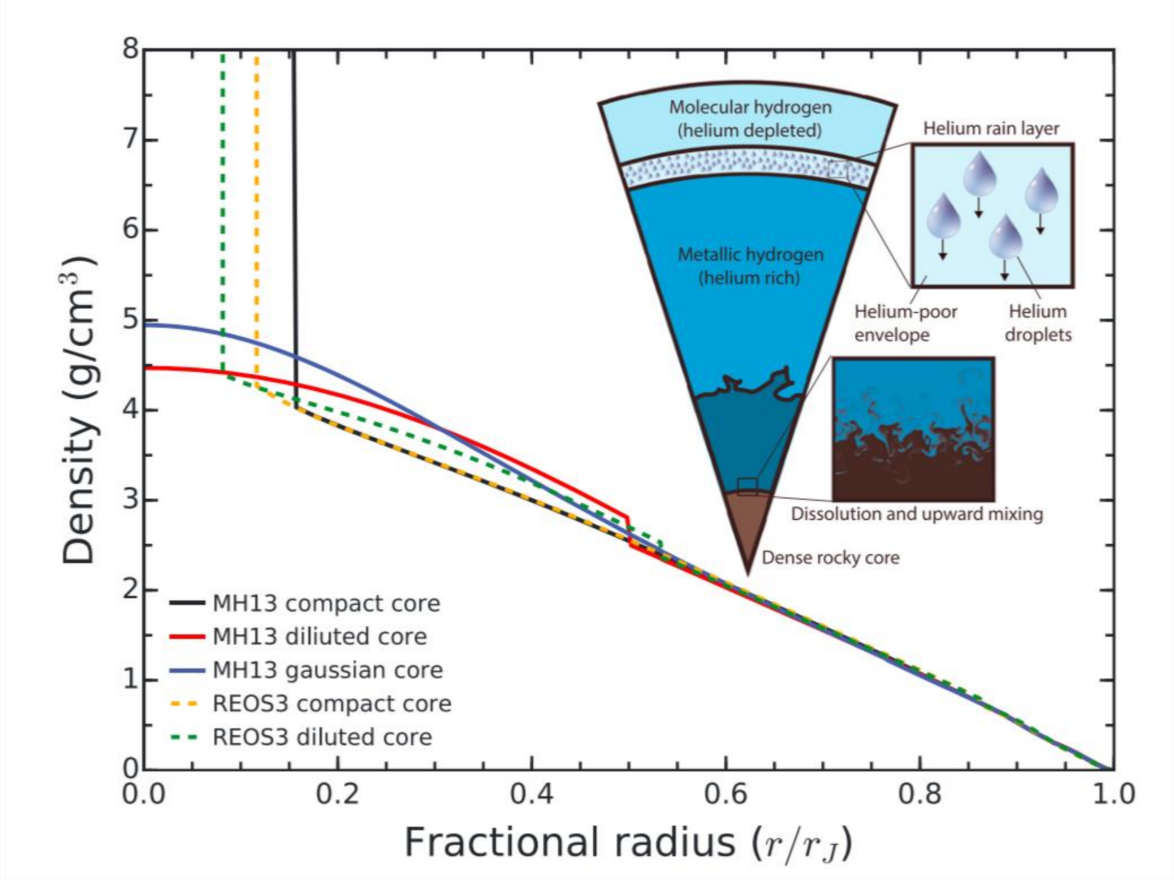
Composition Gradients in Giant Planets



Helled & Stevenson 2017



Debras & Chabrier 2019



Wahl+ 2017

When does the atmospheric composition represent the bulk?

Planetary Evolution with MESA*

*mesa.sourceforge.net

Long-term evolution of gas giants with MESA:

- Solve the structure equations under spherical hydrostatic equilibrium (1D).
- Follow energy transport/mixing through the evolution.

Adapting MESA for planetary evolution:

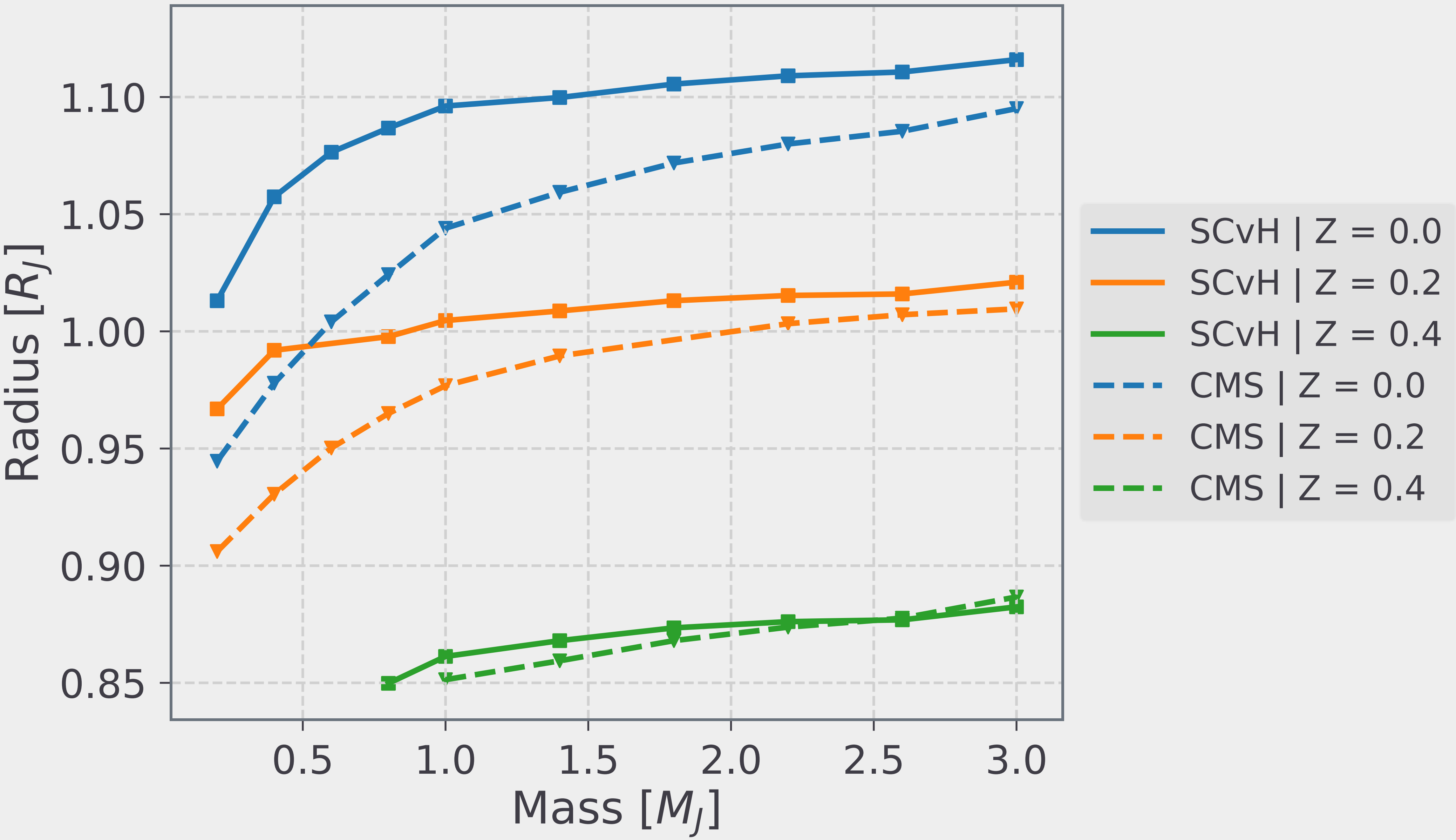
- Planetary evolution has different requirements with regards to modelling the microphysics.
- ***We implemented a new equation of state to model mixtures of H, He and a water/rock*** (Vazan et al. 2013).

Equation of state for hydrogen/helium:

- SCvH (Saumon, Chabrier & van Horn 1995)
- CMS (Chabrier, Mazavet & Soubiran 2019)

CMS has a higher density for hydrogen in for some pressures/temperatures, which ***can lead to more compact gas giants***.

Effects of the H/He Equation of State



Motivation:

Linking atmospheric and bulk composition, and understanding when the atmospheric metallicity represents the bulk.

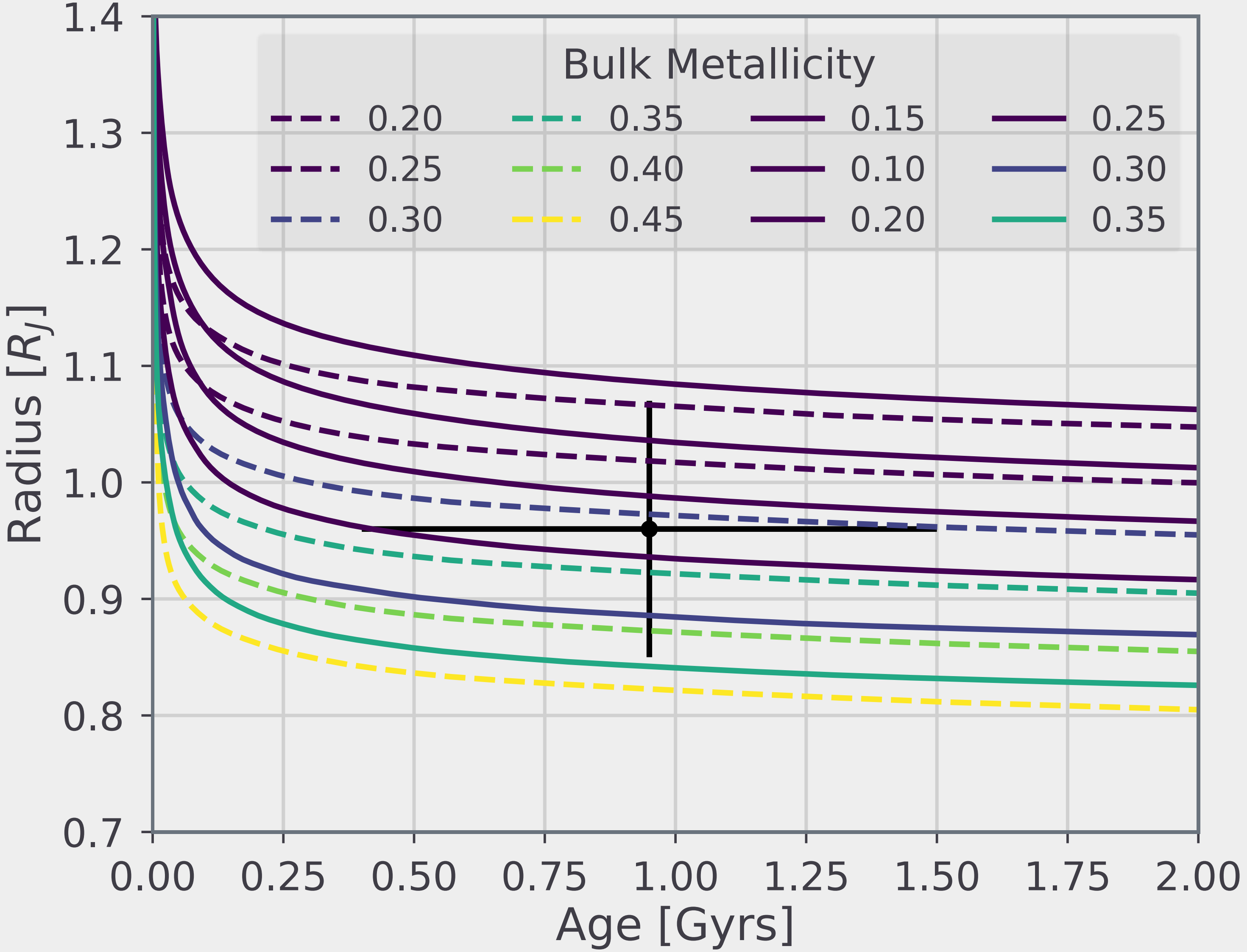
- Identify ARIEL targets whose atmospheric measurements can reduce the uncertainty on the bulk metallicity the most.
- Guide target selection.

Two test cases: Kepler-45b (0.51 M_J) and WASP 130b (1.23 M_J)

1. Find out the range of bulk metallicities that is consistent with observational uncertainties, using different model assumptions.
2. Calculate evolution models with heavy elements distributed in a composition gradient and follow the mixing/envelope enrichment.
3. Compare envelope vs. bulk metallicity at the planet's mean age.

Step 1: Uncertainty in Bulk Metallicity

Kepler-45b: $M = 0.51 \pm 0.09\ M_J, R = 0.96 \pm 0.11$, Age: 0.4 – 1.5 Gyrs



Step 3: Guiding ARIEL target selection

Kepler 45b: Bulk Metallicity Range: 0.10 – 0.40

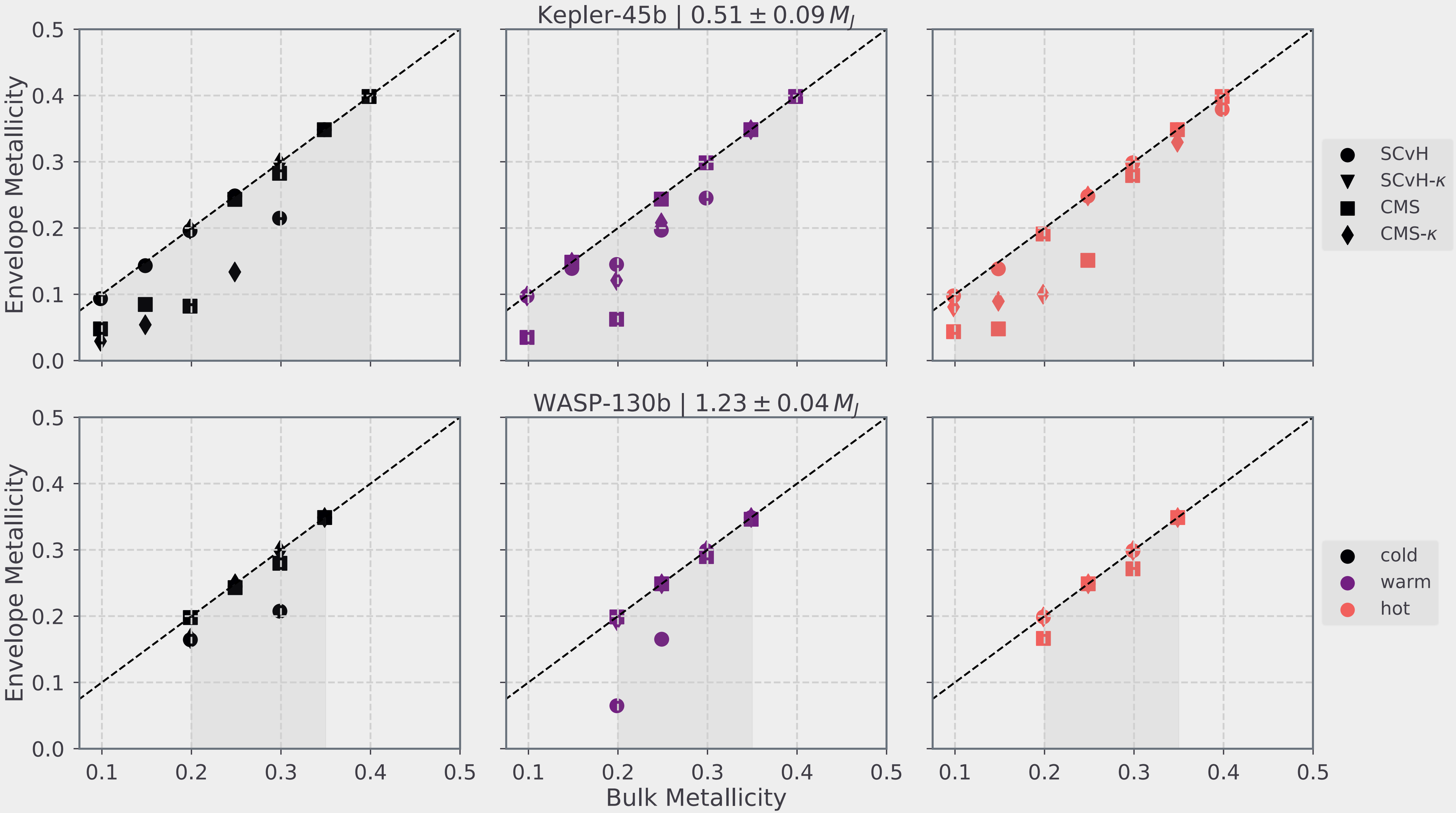
Cold	**Measured Z**	**Z Range**	**Warm**	**Measured Z**	**Z Range**	**Hot**	**Measured Z**	**Z Range**
	0.05	0.10 – 0.15		0.05	0.10 – 0.15		0.05	0.10 – 0.20
	0.10	0.10 – 0.20		0.10	0.10 – 0.20		0.10	0.10 – 0.30
	0.15	0.15 – 0.25		0.15	0.15 – 0.20		0.15	0.15 – 0.25
	0.20	0.20 – 0.30		0.20	0.25		0.20	0.20
	0.25	0.25 – 0.30		0.25	0.25 – 0.30		0.25	0.25
	0.30	0.30		0.30	0.30		0.30	0.30
	0.35	0.35		0.35	0.35		0.35	0.35
	0.40	0.40		0.40	0.40		0.40	0.40

Step 3: Guiding ARIEL target selection

WASP-130b: Bulk Metallicity Range: 0.15 – 0.35

Cold	**Measured Z**	**Z Range**	**Warm**	**Measured Z**	**Z Range**	**Hot**	**Measured Z**	**Z Range**
	-	-		0.05	0.20		-	-
	0.15	0.20		0.15	0.15 – 0.25		0.15	0.20
	0.20	0.20 – 0.30		0.20	0.20		0.20	0.20
	0.25	0.25		0.25	0.25		0.25	0.25 – 0.30
	0.30	0.20 – 0.30		0.30	0.30		0.30	0.30
	0.35	0.35		0.35	0.35		0.35	0.35

Step 2: Envelope vs. Bulk Metallicity

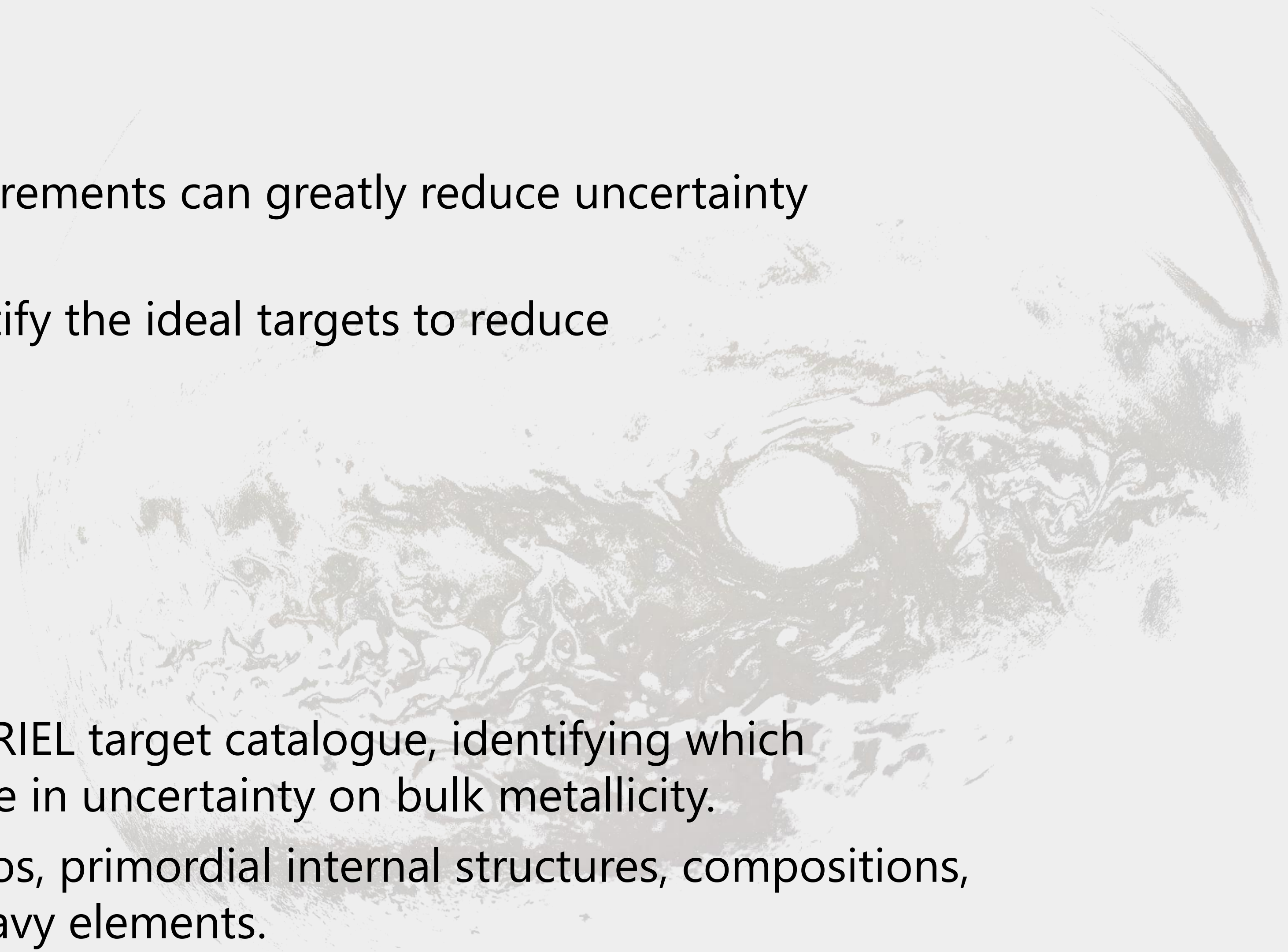


Kepler-45b | $0.51 \pm 0.09\,M_J$

WASP-130b | $1.23 \pm 0.04\,M_J$

Conclusions

- ARIEL atmospheric metallicity measurements can greatly reduce uncertainty in the bulk metallicity.
- This can guide target selection, identify the ideal targets to reduce uncertainty in the bulk metallicity.



Future Work

- Perform calculations for the entire ARIEL target catalogue, identifying which candidates yield the biggest decrease in uncertainty on bulk metallicity.
- Consider different formation scenarios, primordial internal structures, compositions, and various compositions for the heavy elements.
- Link to other observational constraints (luminosity, age, etc.)